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Tjæreborg Wind Turbine (Esbjerg)
First dynamic inflow measurement

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Summary :

This paper presents the first measured timeseries for the Tjæreborg Wind Turbine during operation with stepwise pitch angle changes.

1. Measured time series.

The first experiment to investigate the dynamic wake effects from pitch angle changes on the Tjæreborg Wind Turbine was done April 12, 1991. At the time, the equipment to produce automatic pitch steps was not yet available, so the pitch was changed manually by the control system keyboard. However, with this procedure the pitch rate was fixed at only 1 deg/sec. As it was considered a preliminary test only one time series of 10 minutes was recorded. The test conditions were not ideal either as the wind speed was only 7 to 8 m/s.

Page 5 and 6 of this paper show data from the original time series. The flapwise moments are measured at R = 2.75 m at all 3 blades. The measured moments have been corrected for zero-point errors by comparing the mean values with calculated values for the mean wind speed derived from the measured mean power and the measured power curve, thereby using the wind turbine as anemometer. This procedure has been shown to be quite accurate in cases where the zero points could be checked by stopping the turbine. When the flapwise moments are compared to calculated aerodynamic moments it should be noted, that the actual moments are reduced by the centrifugal stiffening of the blades. The reduction has been estimated to 9%.

The measured pitch angle shows an offset of 0.5 deg. compared to the ones commanded. The control system and the measurement system obviously disagree, although they both get the signal from the same transducer. At present, it is not known which one is the correct one, so no corrections have been made to the measured values.

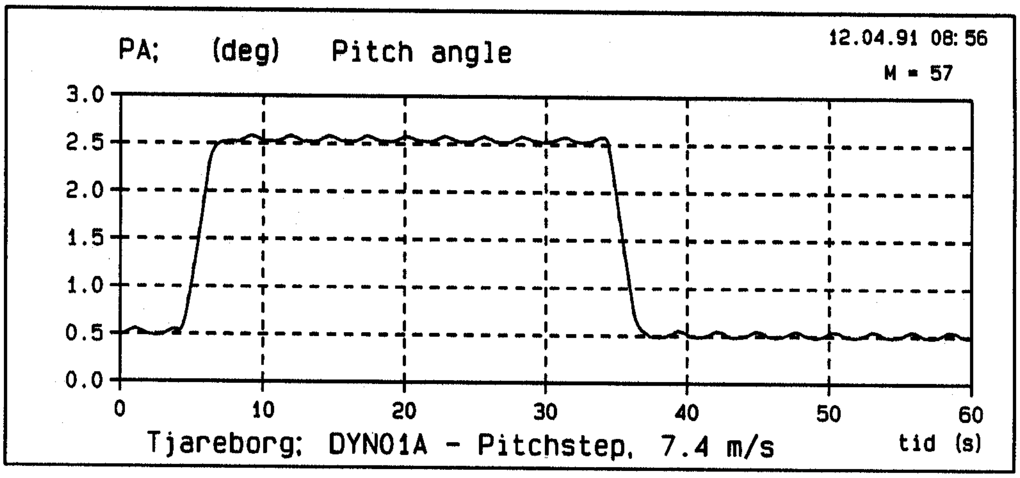
2. Calculation of average step response.

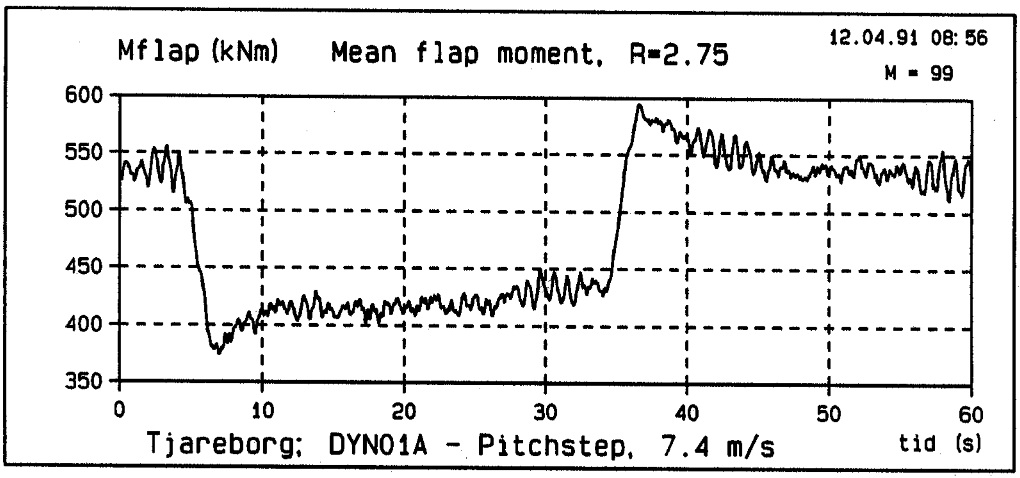
In order to extract the most information about the dynamic wake effects from the measured time series, the following averaging procedure has been performed.

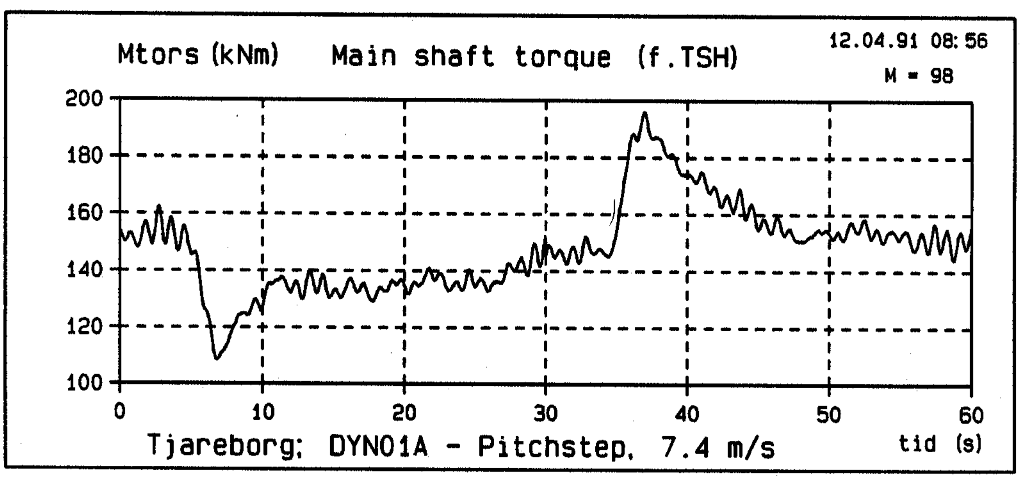
First the time trace for the pitch angle is searched for the times where it crosses upwards through the level of 1.0 deg. The complete time series is then divided into 9 segments of 30 sec. duration each starting 5 sec. before the level crossing. A new time series is constructed as the average of the 9 series in the sense, that the value of each sensor signal at a given time is the average of the 9 individual values from the 9 time series at the same time relative to the pitch angle level crossing. A new sensor signal is calculated as the mean value of the 3 averaged flapwise moments to further reduce the influence of turbulence, wind shear and tower shadow. Finally, a synthetic signal for the main shaft torsion is calculated from the measured torsion of the high speed shaft by multiplication with the gear box speed ratio, as the real main shaft torsion sensor is unreliable.

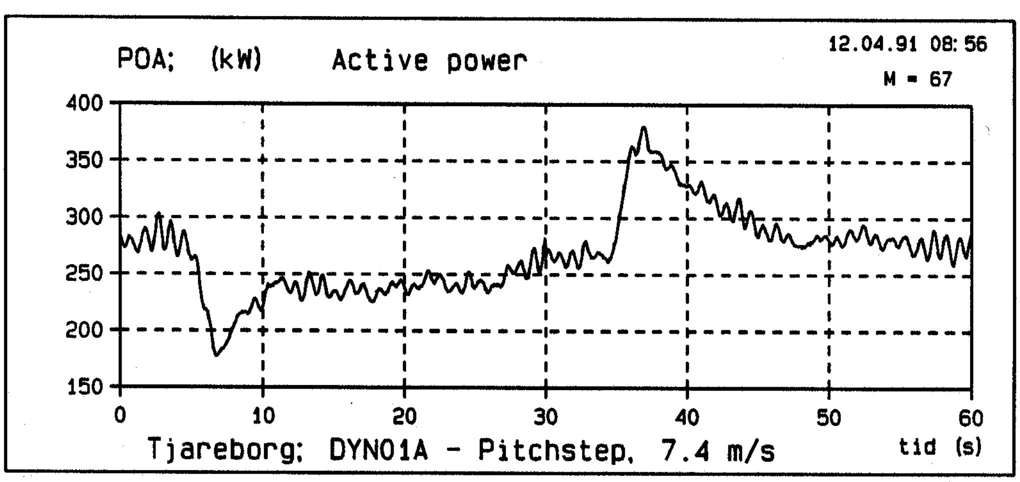
The above procedure is repeated for the decreasing pitch steps determined as crossing down through 2.0 deg. The resulting averaged time series is then appended to the first, starting at t = 30 sec.

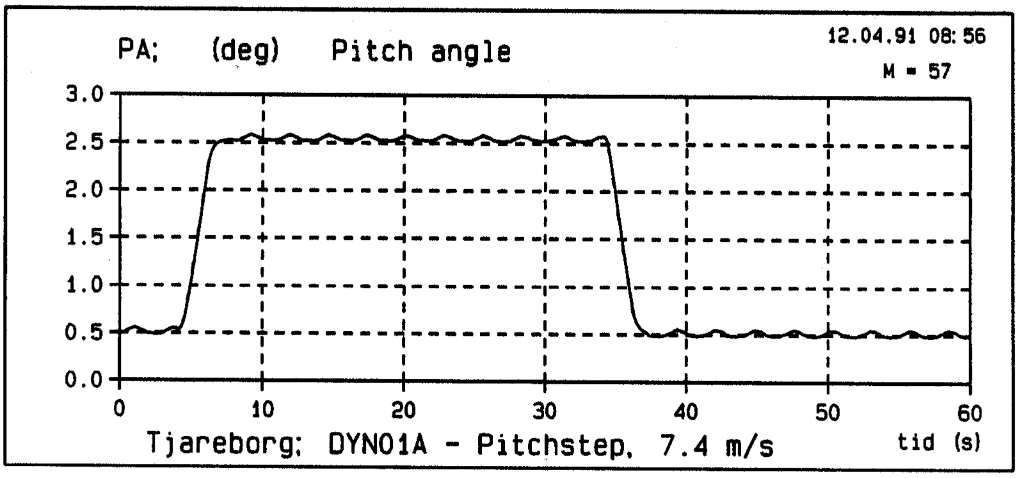
The averaged time series are shown on page 3 and 4. They are showing clear indications of dynamic wake effects, but also a surprising large amount of 1P or 3P variations. This is caused by the pitch change repetition frequency being very close to a integer fraction of the rotational frequency. This will be avoided in future experiments by changing the pitch frequency slightly. It is also hoped to improve future results by recording at least 3 consecutive 10 min series at each experiment.

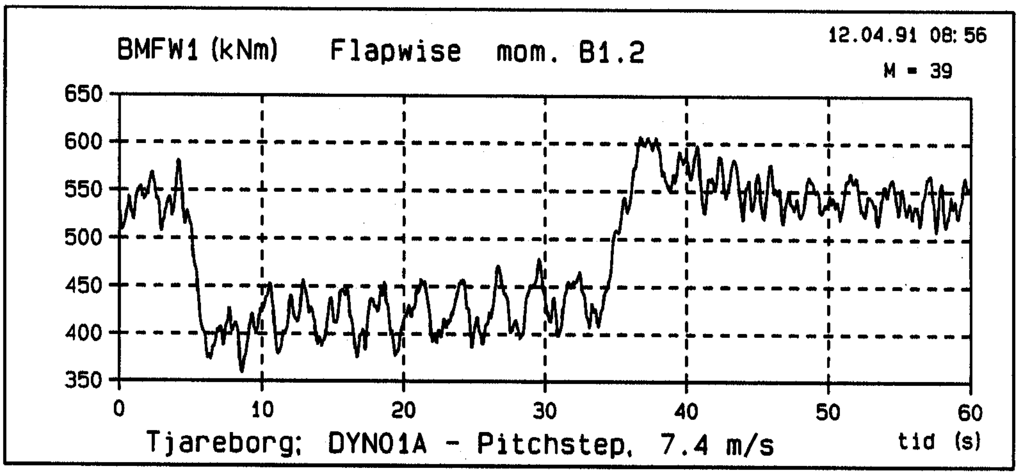

PA; (deg) Pitch angle
12.04.91 08:56
M = 57
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
10
20
30
40
50
60
Tjareborg: DYN01A - Pitchstep, 7.4 m/s
tid (s)

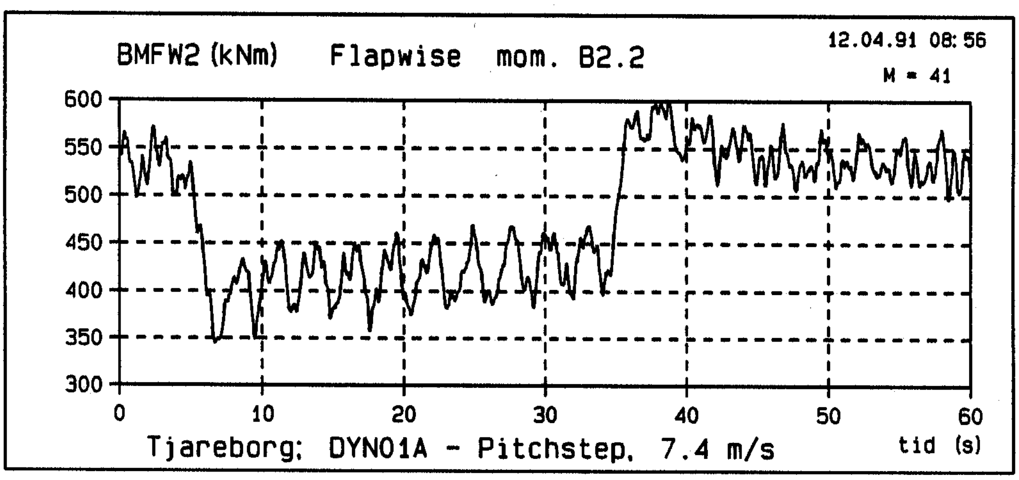

Mflap (kNm) Mean flap moment, R=2.75
12.04.91 08:56
M = 99
600
550
500
450
400
350
0
10
20
30
40
50
60
Tjareborg: DYN01A - Pitchstep, 7.4 m/s
tid (s)

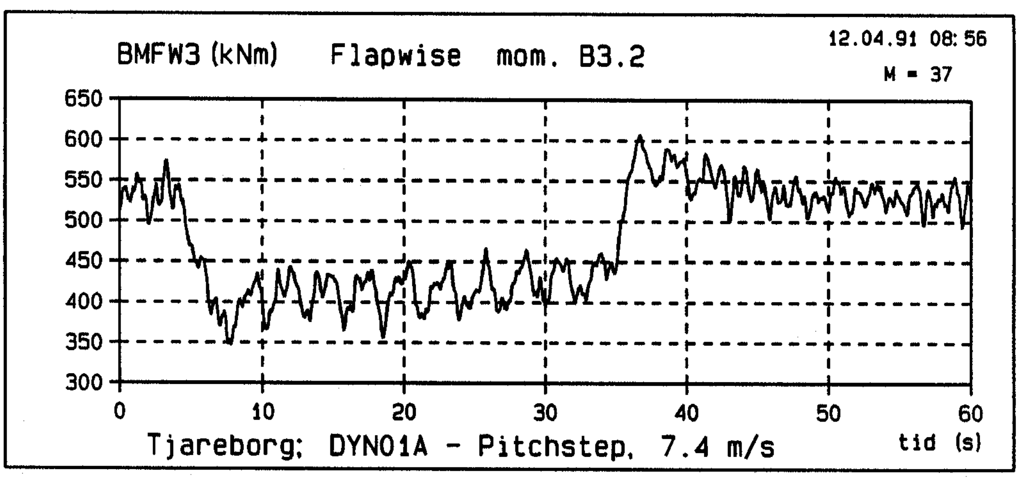

Mtors (kNm) Main shaft torque (f.TSH)
12.04.91 08:56
M = 98
200
180
160
140
120
100
0
10
20
30
40
50
60
Tjareborg: DYN01A - Pitchstep, 7.4 m/s
tid (s)

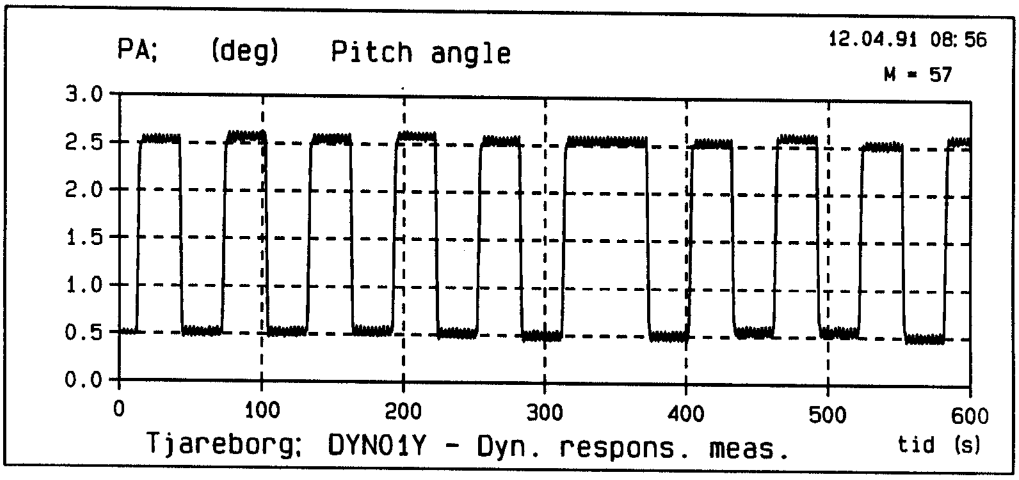

POA; (kW) Active power
12.04.91 08:56
M = 67
400
350
300
250
200
150
0
10
20
30
40
50
60
Tjareborg: DYN01A - Pitchstep, 7.4 m/s
tid (s)

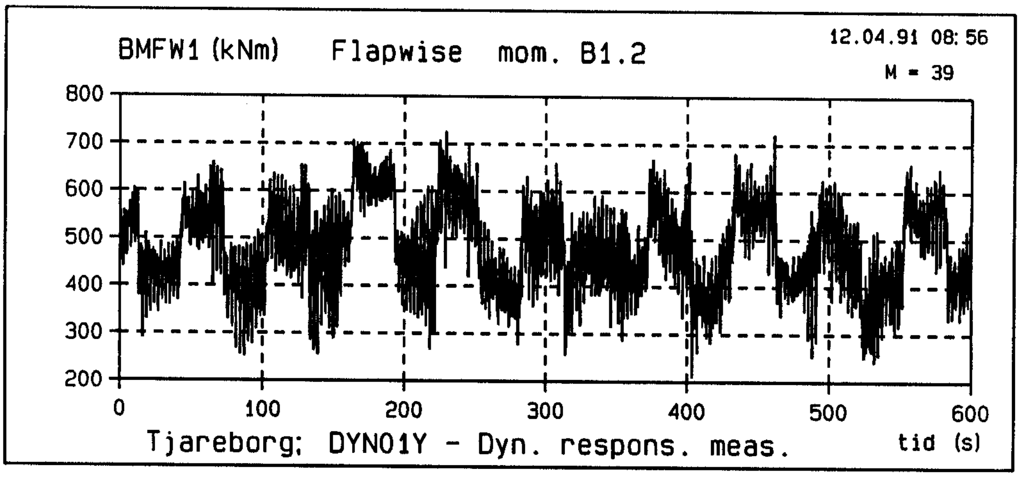

PA; (deg) Pitch angle
12.04.91 08:56
M = 57
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
10
20
30
40
50
60
Tjareborg; DYN01A - Pitchstep, 7.4 m/s
tid (s)

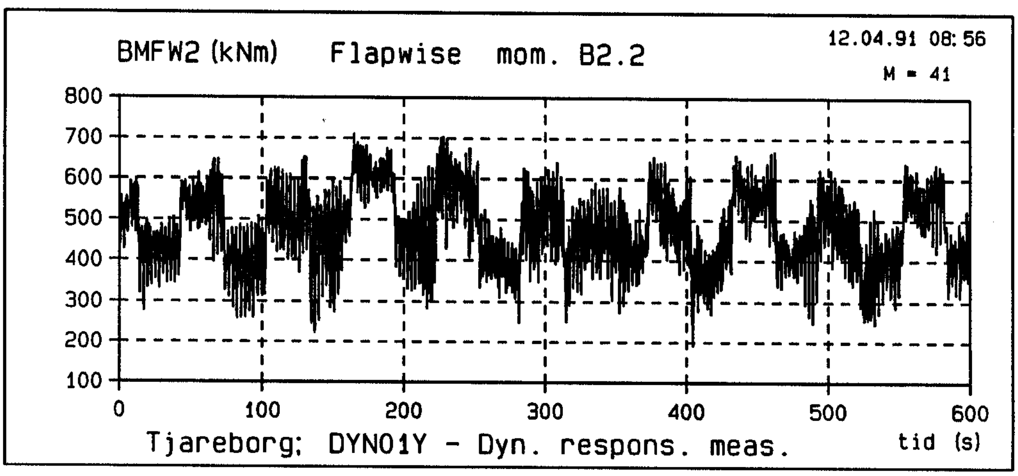

BMFW1 (kNm) Flapwise mom. B1.2
12.04.91 08:56
M = 39
650
600
550
500
450
400
350
0
10
20
30
40
50
60
Tjareborg; DYN01A - Pitchstep, 7.4 m/s
tid (s)

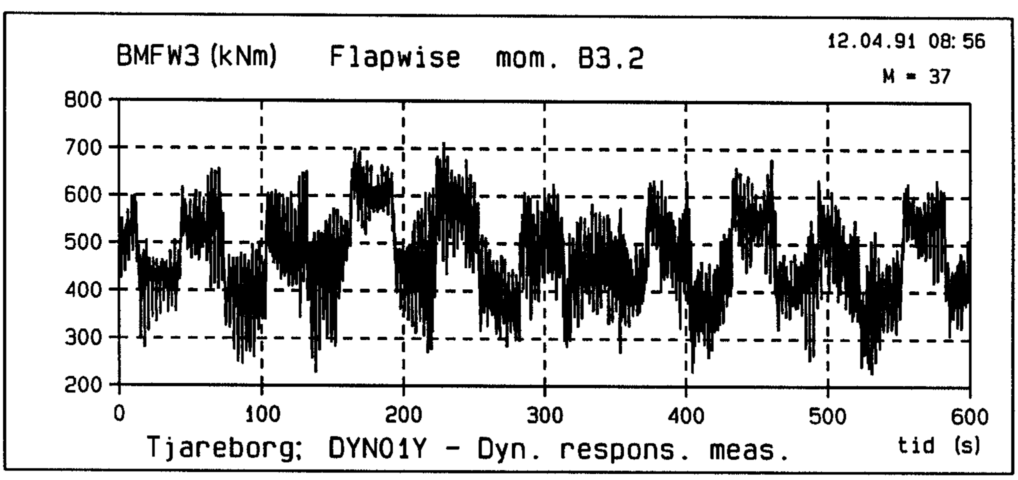

BMFW2 (kNm) Flapwise mom. B2.2
12.04.91 08:56
M = 41
600
550
500
450
400
350
300
0
10
20
30
40
50
60
Tjareborg; DYN01A - Pitchstep, 7.4 m/s
tid (s)

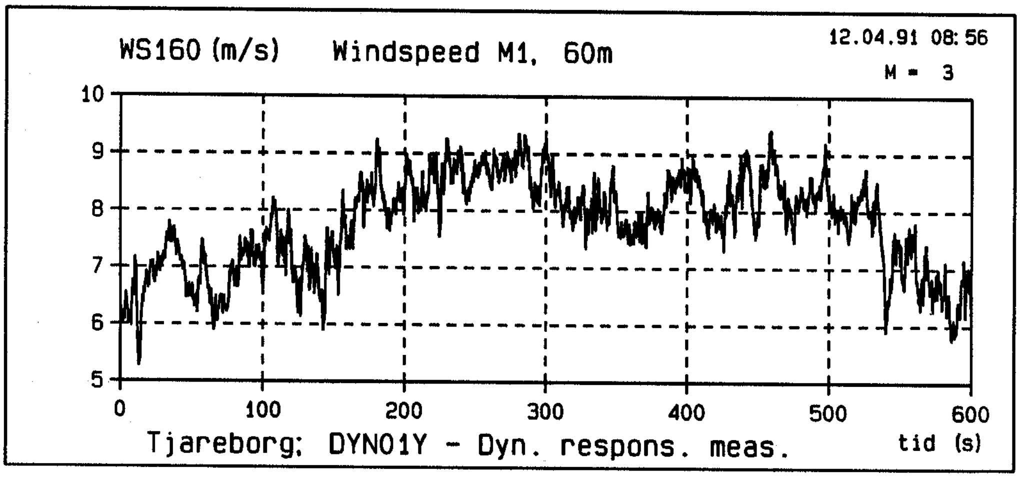

BMFW3 (kNm) Flapwise mom. B3.2
12.04.91 08:56
M = 37
650
600
550
500
450
400
350
300
0
10
20
30
40
50
60
Tjareborg; DYN01A - Pitchstep, 7.4 m/s
tid (s)

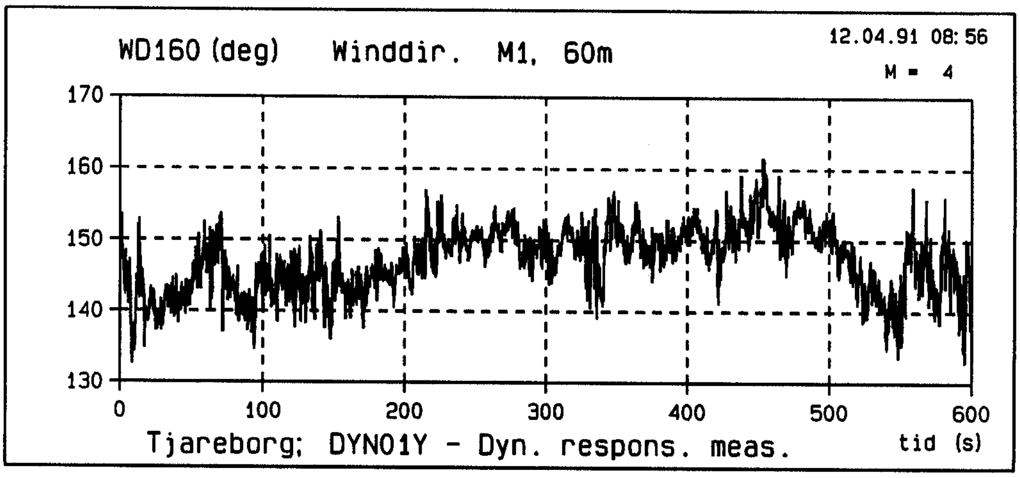

PA; (deg) Pitch angle
12.04.91 08:56
M = 57
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
100
200
300
400
500
600
Tjareborg; DYN01Y - Dyn. respons. meas.
tid (s)

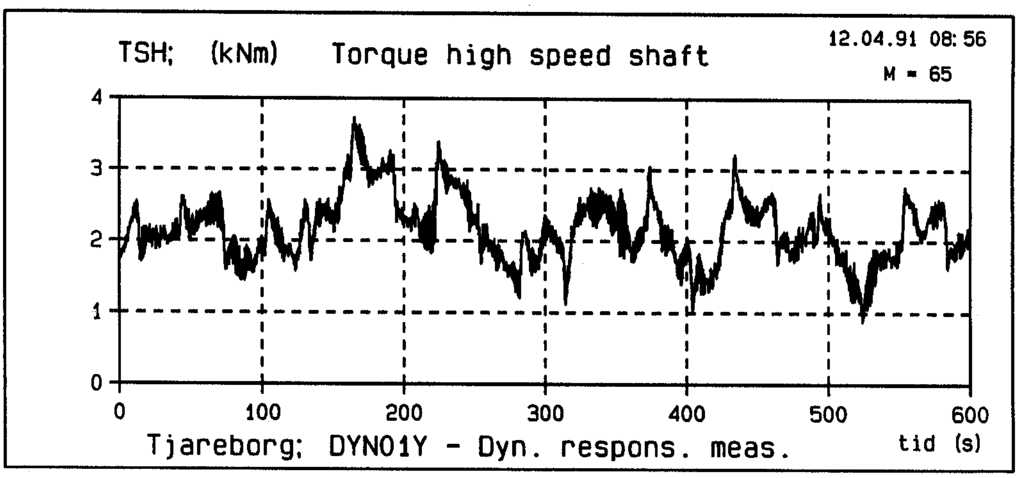

BMFW1 (kNm) Flapwise mom. B1.2
12.04.91 08:56
M = 39
800
700
600
500
400
300
200
0
100
200
300
400
500
600
Tjareborg; DYN01Y - Dyn. respons. meas.
tid (s)

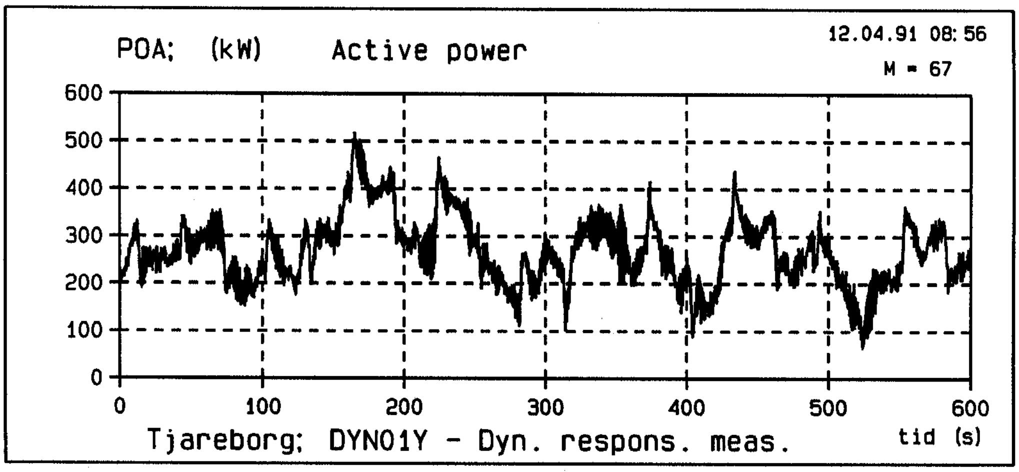

BMFW2 (kNm) Flapwise mom. B2.2
12.04.91 08:56
M = 41
800
700
600
500
400
300
200
100
0
100
200
300
400
500
600
Tjareborg; DYN01Y - Dyn. respons. meas.
tid (s)


BMFW3 (kNm) Flapwise mom. B3.2
12.04.91 08:56
M = 37
800
700
600
500
400
300
200
0
100
200
300
400
500
600
Tjareborg; DYN01Y - Dyn. respons. meas.
tid (s)


WS160 (m/s) Windspeed M1, 60m
12.04.91 08:56
M = 3
10
9
8
7
6
5
0
100
200
300
400
500
600
Tjareborg; DYN01Y - Dyn. respons. meas.
tid (s)


WD160 (deg) Winddir. M1, 60m
12.04.91 08:56
M = 4
170
160
150
140
130
0
100
200
300
400
500
600
Tjareborg; DYN01Y - Dyn. respons. meas.
tid (s)


TSH; (kNm) Torque high speed shaft
12.04.91 08:56
M = 65
4
3
2
1
0
0
100
200
300
400
500
600
Tjareborg; DYN01Y - Dyn. respons. meas.
tid (s)


POA; (kW) Active power
12.04.91 08:56
M = 67
600
500
400
300
200
100
0
0
100
200
300
400
500
600
Tjareborg; DYN01Y - Dyn. respons. meas.
tid (s)